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TECHNICAL NOTE

No. 1059

EFFECTS OF TIP DIHEDRAL ON LATERAL STABILITY AND
CONTROL CHARACTERISTICS AS DETERMINED BY TESTS
OF A DYNAMIC MODEL IN THE LANGLEY FREE-FLIGHT TUNNEL

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SUMMARY

The effects of tip dihedral on lateral stability and control characteristics were investigated by flight tests of models in the Langley free-flight tunnel. The geometric dihedral angle was varied over a wide range with the dihedral breaks at the wing root and at 50 and 75 percent of the semispan outboard of the wing root. The vertical-tail area was varied from 5 to 15 percent of the wing area. The model was flown with various combinations of these variables at lift coefficients from 0.4 to 1.0.

At low lift coefficients and at similar values of effective dihedral and directional stability no differences were noted in the flying characteristics with full-span or tip dihedral. At high lift coefficients, however, large angles of tip dihedral caused lightly damped lateral oscillations (predominantly rolling) which were considered objectionable and possibly dangerous. This abnormal lateral oscillation was believed to be caused by a reduction of the damping in roll due to early stalling at the dihedral juncture.

INTRODUCTION

Pilots have reported poor lateral-flight behavior at low speeds of airplanes which have tip dihedral. An investigation was therefore made in the Langley free-flight tunnel to determine the effects of tip dihedral on lateral-flight characteristics.

The investigation consisted primarily in flight tests of similar models having dihedral breaks at various spanwise locations. Tests were made over a range of dihedral angle at full-span, half-span, and quarter-span dihedrals (that is, with dihedral breaks at 0, 50, and 75 percent of the semispan outboard of the wing root). In order that the investigation might be quite general, a range of vertical-tail size from 5 to 15 percent of the wing area was used for each dihedral configuration. The results of the tests are presented in the form of qualitative ratings of the general flight behavior of the models to show the effects of tip dihedral as compared with a full-span dihedral.

SYMBOLS

m	mass of model, slugs
S	wing area, square feet (2.67 sq ft)
S _t	vertical-tail area, square feet
b	wing span, feet
V	airspeed, feet per second
q	dynamic pressure, pounds per square foot $(\frac{1}{2}\rho V^2)$
t	time, seconds
k _x	radius of gyration of model about longitudinal axis, feet
k _z	radius of gyration of model about vertical axis, feet
R	Routh's discriminant
E	coefficient in stability quartic equation, given in reference 1
r	yawing angular velocity, radians per second
ρ	mass density of air, slugs per cubic foot
β	angle of sideslip, degrees

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ψ	angle of yaw, degrees
p	rolling angular velocity, radians per second
Γ	geometric dihedral angle of mean thickness line, degrees
ϕ	angle of bank, degrees
μ	airplane relative-density factor $\left(\frac{m}{\rho S b}\right)$
C_L	lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$
C_l	rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb}\right)$
C_Y	lateral-force coefficient $\left(\frac{\text{Lateral force}}{qS}\right)$
C_n	yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$
$C_{l\beta}$	rate of change of rolling-moment coefficient with angle of sideslip, per degree $\left(\frac{\partial C_l}{\partial \beta}\right)$
$C_{Y\beta}$	rate of change of lateral-force coefficient with angle of sideslip, per degree $\left(\frac{\partial C_Y}{\partial \beta}\right)$
$C_{n\beta}$	rate of change of yawing-moment coefficient with angle of sideslip, per degree $\left(\frac{\partial C_n}{\partial \beta}\right)$
C_{lp}	rate of change of rolling-moment coefficient with rolling-angular-velocity factor $\left(\frac{\partial C_l}{\partial (pb/2V)}\right)$
C_{np}	rate of change of yawing-moment coefficient with rolling-angular-velocity factor $\left(\frac{\partial C_n}{\partial (pb/2V)}\right)$
C_{lr}	rate of change of rolling-moment coefficient with yawing-angular-velocity factor $\left(\frac{\partial C_l}{\partial (rb/2V)}\right)$

C_{n_r} rate of change of yawing-moment-coefficient with
yawing-angular-velocity factor $\left(\frac{\partial C_n}{\partial \frac{rb}{2V}} \right)$

APPARATUS

The investigation was carried out in the Langley free-flight tunnel, which is equipped for testing free-flying airplane models. A complete description of the tunnel and its operation is given in reference 2. Force tests to determine the static lateral stability derivatives were made on the Langley free-flight-tunnel six-component balance, described in reference 3. This balance rotates with the model in yaw, so that all forces and moments are measured with respect to the stability axes. The stability axes are an orthogonal system of axes having its origin at the center of gravity in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

The control used on free-flight-tunnel models is a "flicker" (full-on or full-off) system. (See reference 2.) During any one flight the control deflections in the full-on positions are constant and the amount of control applied to the model is regulated by the number of control deflections used and by the length of time the control is held deflected.

Two free-flying models were used for the investigation. One model had a dihedral break at the root and at 50 percent of the semispan. The other had a dihedral break at the root and at 75 percent of the semispan. Although the models used in the tests were not scale models of any particular airplane, they approximately represented $\frac{1}{10}$ -scale models of current conventional fighter airplanes. The models were of high-midwing design with an angle of sweepback of 0° of the 50-percent-chord line, taper ratio of 0.5, and span of 4 feet. A three-view drawing and photographs of the models are shown as figures 1 to 4. The models used were similar in arrangement to the model used for the tests of reference 4. Four vertical tails were used to vary the directional stability of the models. (See fig. 2.)

The model relative-density factor and radii of gyration were:

μ	8.10
k_X/b	0.161
k_Z/b	0.241

TESTS

Scope of Tests

Flight tests of the model were made at a lift coefficient of 1.0 for a range of dihedral angle at the various spanwise locations and for a range of vertical-tail area which are considered representative of present-day limits. The dihedral angle was varied from -10° to 20° for the full-span-dihedral tests, from -20° to 40° for the half-span-dihedral tests, and from -40° to 40° for the quarter-span-dihedral tests. For the half-span-dihedral and quarter-span-dihedral tests the dihedral angle of the inboard section was maintained at 0° while the dihedral angle was varied from the half-span or quarter-span positions. The vertical-tail area was varied from 5 to 15 percent of the wing area. For test conditions at which the behavior of the models with tip dihedral was abnormal at a lift coefficient of 1.0, additional flight tests were made for a range of lift coefficient from 0.4 to 1.0. The values of C_{l_β} and C_{n_β} corresponding to the various test conditions were determined from force-test data and are presented in figure 5. Stall surveys were made with tufts in order to determine the wing-stall patterns of the models for various dihedral arrangements.

Testing Procedure

The model was flown at each test condition by means of ailerons coupled with rudder. A total aileron travel of 30° was used for all the flight tests. The rudder travels used were selected by visual observation of flight tests as the amount necessary to eliminate the adverse yawing in aileron rolls.

The stability and control characteristics were determined from the free-flight-tunnel pilot's observations and motion-picture records of flights. The general flight-behavior ratings were based on the pilot's opinion recorded for each test condition. Each rating was based on a number of separate flights. Although the accuracy of these ratings depended upon the pilot's ability to recognize unsatisfactory conditions, it is believed that the ratings give a qualitative indication of the effect of changes of the variables involved.

CALCULATIONS

Boundaries for neutral spiral stability ($E = 0$) and neutral oscillatory stability ($R = 0$) were calculated over the test range by means of the stability equations of reference 1 and are shown in figures 6 and 8.

Values of the lateral stability derivative $C_{Y\beta}$ used in the calculations were obtained from force tests of the model. The value of the yawing rotary derivative C_{n_r} was obtained from free-oscillation tests of the model by the method described in reference 5. The other rotary derivatives C_{l_p} , C_{n_p} , and C_{l_r} were estimated from the charts of reference 6 and the formulas of reference 7. The values of the mass characteristics m , k_x , and k_z were measured for the model.

RESULTS AND DISCUSSION

The results of the flight tests at a lift coefficient of 1.0 are presented in figure 6 in the form of qualitative ratings of the general flight behavior of the model. The flight-behavior ratings and the variations of the ratings with $C_{l\beta}$ and $C_{n\beta}$, as shown in figure 6(a)

for the models with full-span dihedral, are considered normal inasmuch as they are quite similar to the ratings obtained in previous free-flight-tunnel tests. These results will therefore be used as a standard by which to compare the results of the tests of models with half-span and quarter-span dihedral.

The behavior of the model with half-span dihedral (fig. 6(b)) was similar to that of the models with full-span dihedral for the same values of $C_{l\beta}$ and $C_{n\beta}$.

With the quarter-span dihedral, however, the model was more difficult to fly at a lift coefficient of 1.0 than it was with full-span dihedral as shown by a comparison of the ratings of figures 6(a) and 6(c) for the same values of $C_{l\beta}$ and $C_{n\beta}$. This difference in the flying characteristics was most pronounced at lower values of $C_{n\beta}$ and higher values of effective dihedral, particularly for the model with 40° quarter-span dihedral and vertical tail 5 percent of the wing area ($C_{l\beta} = -0.0020$ and $C_{n\beta} = 0.00075$). The model, at a lift coefficient of 1.0 and with a quarter-span dihedral of 40°, performed a lightly damped lateral oscillation which was predominantly rolling. As the directional stability was reduced for this dihedral arrangement, the rolling oscillation became more violent and at the lowest value of directional stability tested ($C_{n\beta} = 0.00075$) the motion became so violent that the model was barely flyable. This oscillation differed from the type of oscillation usually obtained with low directional stability and high effective dihedral in that the rolling was much more severe and of shorter period with smaller sidewise displacement. The model in these oscillations described a rapid "falling-leaf" maneuver. The oscillations were started by normal control deflections and gustiness in the tunnel. The pilot found these oscillations difficult to check and at times may have accidentally reinforced them with ailerons. Figure 7(a) presents a time history of the model in controlled flight at a lift coefficient of 1.0 and a quarter-span dihedral of 40°.

At the lower lift coefficients the model was easier to fly and the rolling oscillations were more heavily damped, as shown in figure 7(b) ($C_L = 0.4$). These lateral flying characteristics at low lift coefficient were considered to be fairly good and figure 7(b) is presented for comparison with the flight record of the model with quarter-span dihedral of 40° at high lift coefficient (fig. 7(a)). Figure 8 presents a comparison

of the flight-behavior ratings for the model with full-span and quarter-span dihedral for lift coefficients of 0.4, 0.7, and 1.0. This figure shows that no appreciable difference existed between the flying characteristics of the quarter-span- and full-span-dihedral models at lower lift coefficients.

The objectionable rolling of the model encountered at a lift coefficient of 1.0 and a quarter-span dihedral of 40° is believed to have been caused by lower damping in roll C_{l_p} than that of the model with full-span dihedral. Stall surveys of the models show that an early stall occurs at the dihedral break of the quarter-span-dihedral model that does not occur on the full-span-dihedral model. (See fig. 9.) In a roll the downgoing wing of the model is at a higher effective angle of attack than that for which the model is trimmed and the upgoing wing is at a lower effective angle of attack. At high lift coefficients, then, the downgoing wing of the quarter-span-dihedral model may be partly stalled and the upgoing wing unstalled, whereas both wings of the full-span-dihedral model are unstalled. Because of this unsymmetrical stalling the quarter-span-dihedral model would be expected to have a lower value of the damping in roll parameter C_{l_p} than

the full-span-dihedral model. This conclusion has been substantiated by the results of full-scale flight tests in which "falling-leaf" oscillations were encountered when early tip stall occurred.

The wing-tip stalling, and consequent reduction of C_{l_p} of the quarter-span-dihedral model would probably be intensified by any adverse yawing which occurred. The discrepancy between the flight ratings for the full-span-dihedral and quarter-span-dihedral models was therefore greater for test conditions having low directional stability than for those having high directional stability. (See fig. 6.)

The low scale at which tests were made must be considered when an analysis is made of the present data, because the stalling at the dihedral break of full-scale airplanes with tip dihedral will not necessarily be the same as for the models tested. It is believed, however, that large angles of tip dihedral will tend to cause poor lateral stability at low speeds and should therefore be avoided.

CONCLUSIONS

Free-flight-tunnel tests of free-flying models have shown that at high lift coefficients tip dihedral may cause a lightly damped lateral oscillation (predominantly rolling), which does not occur with full-span dihedral at similar values of effective dihedral and directional stability. This abnormal lateral oscillation is believed to be caused by a reduction of the damping in roll due to early stalling at the dihedral break. No apparent difference existed between the flying characteristics of the models with full-span and tip dihedral for the lower lift coefficients.

In order to establish definitely the reasons for the poor lateral-stability characteristics at high lift coefficients with tip dihedral, values of the damping in roll parameter C_{lp} should be measured for the various conditions tested, and an independent study of the effect of stall patterns on lateral stability at high lift coefficients should be made.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 12, 1946

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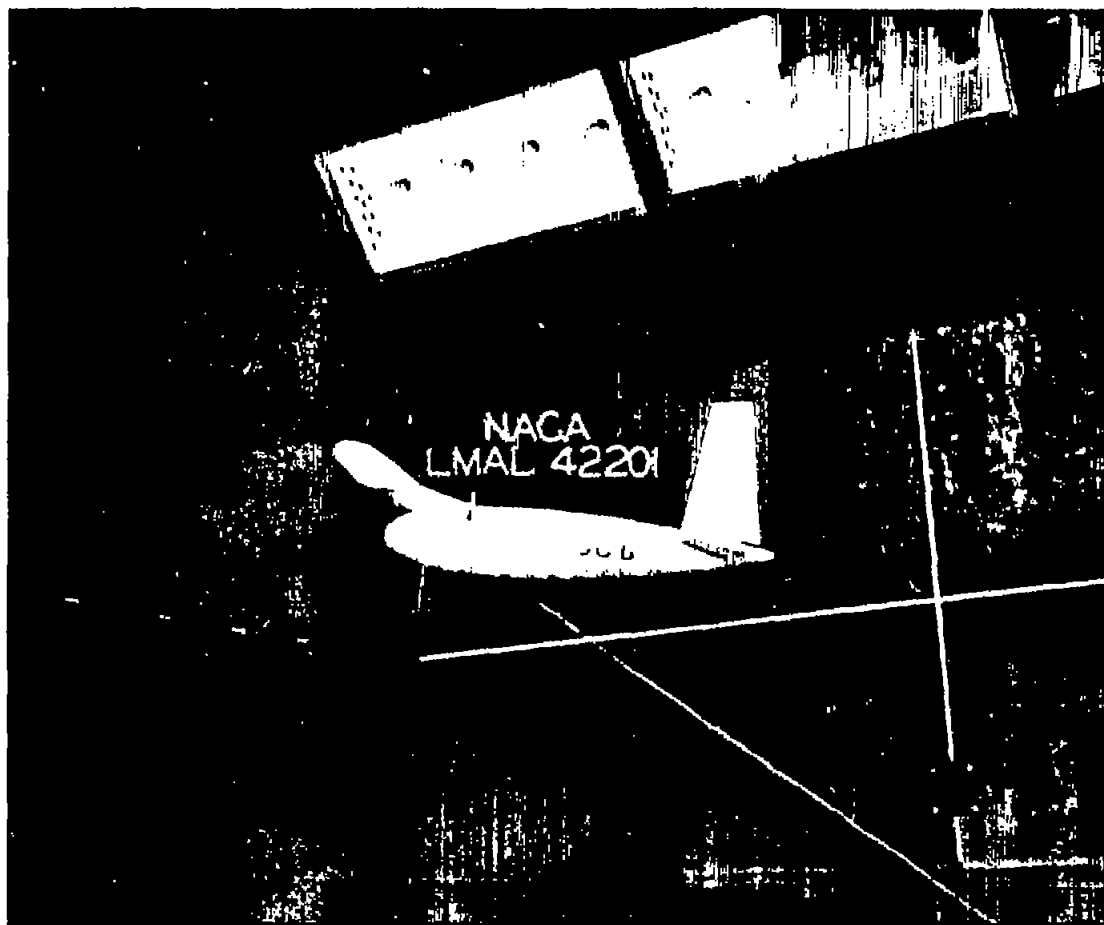


Figure 1.- Test section of Langley free-flight tunnel showing model with tip dihedral in flight.

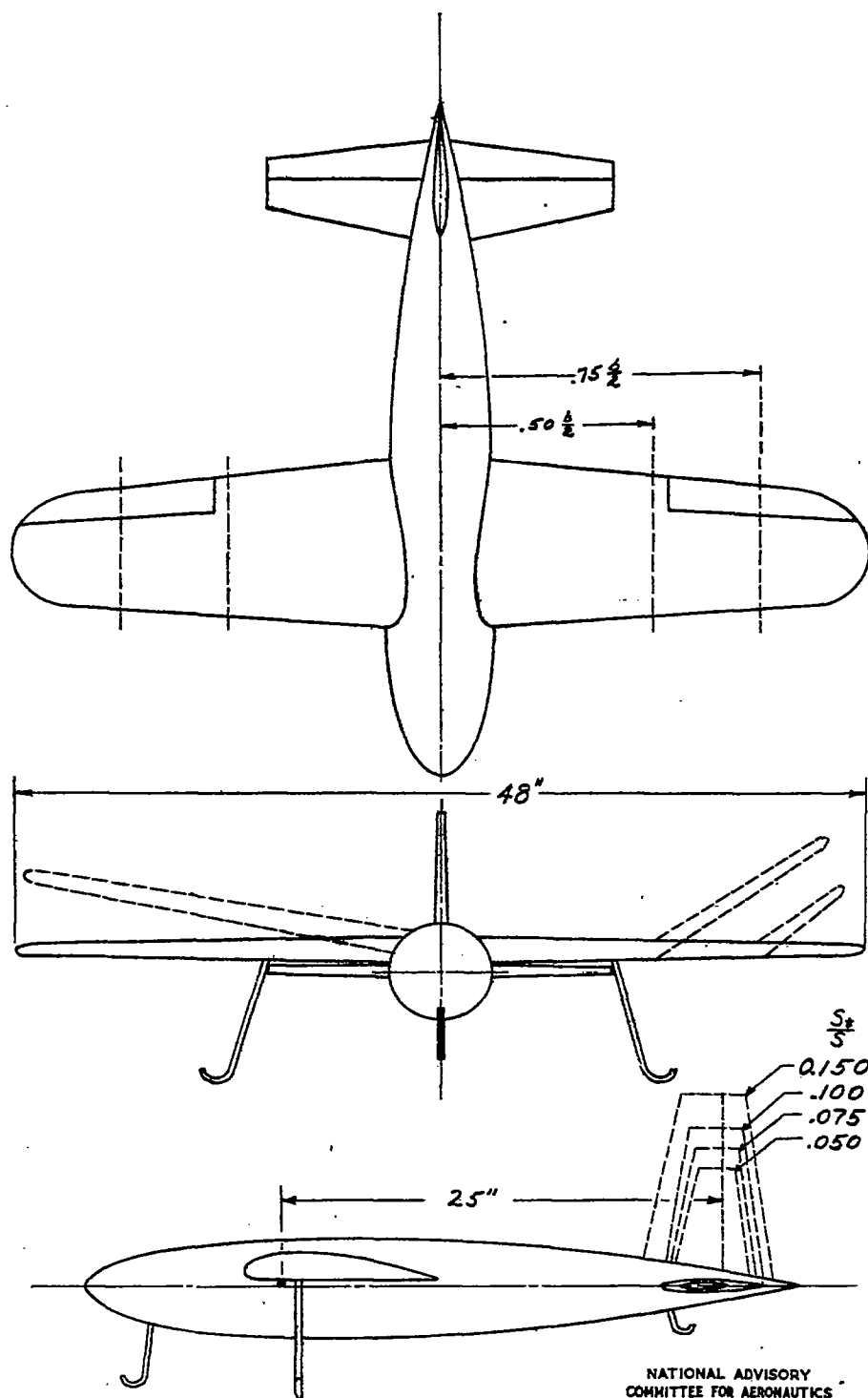
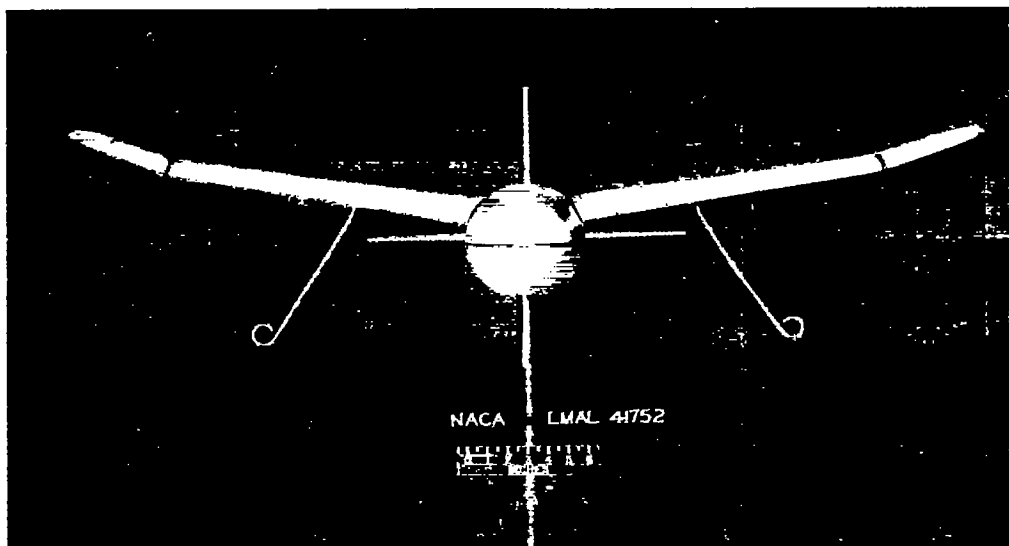
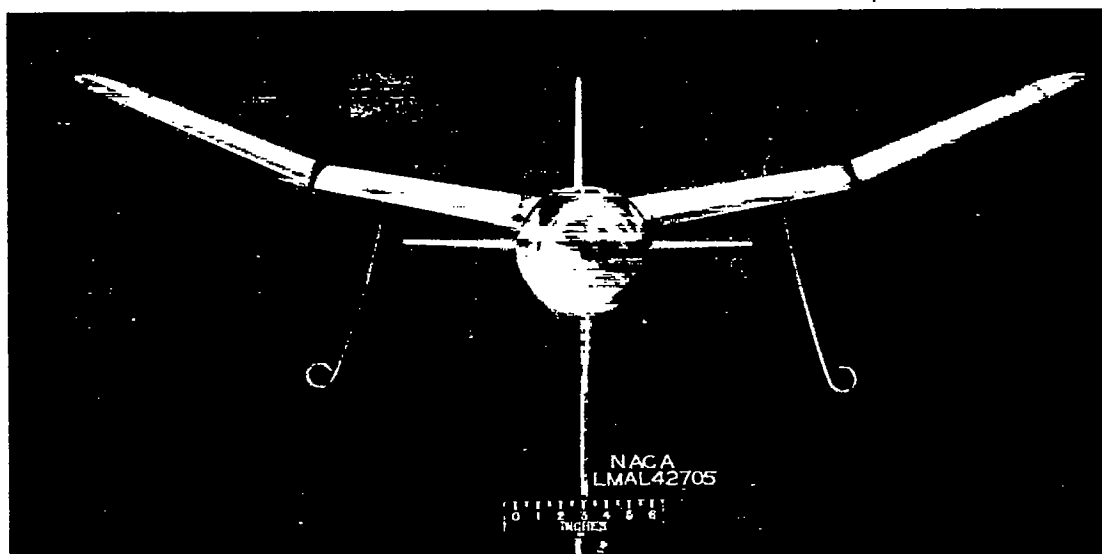


Figure 2.- Three-view sketch of models used in Langley free-flight-tunnel tip-dihedral tests.

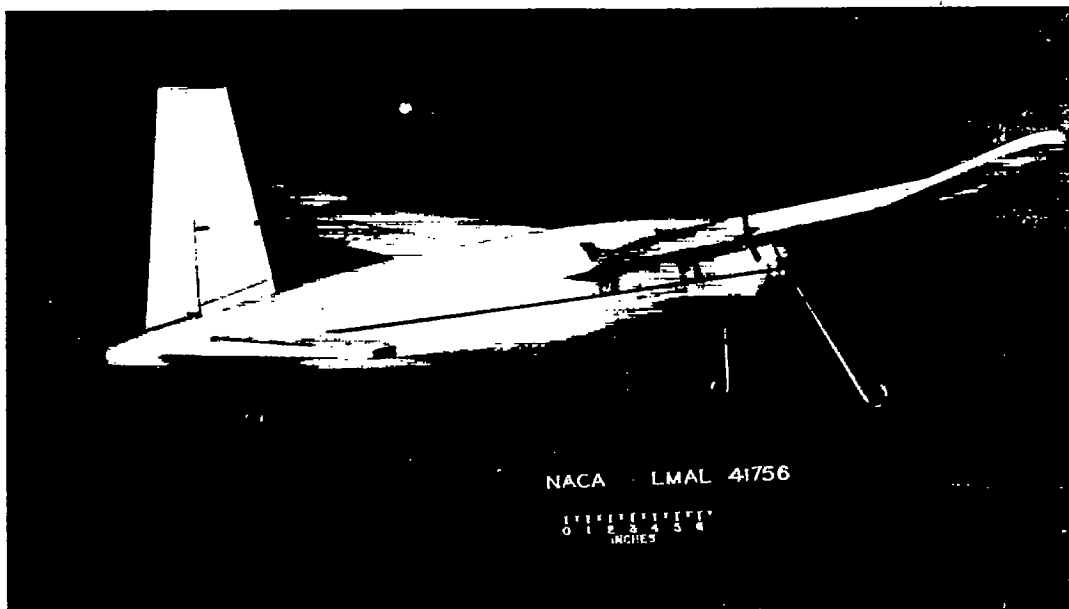


(a) Quarter-span-dihedral model.

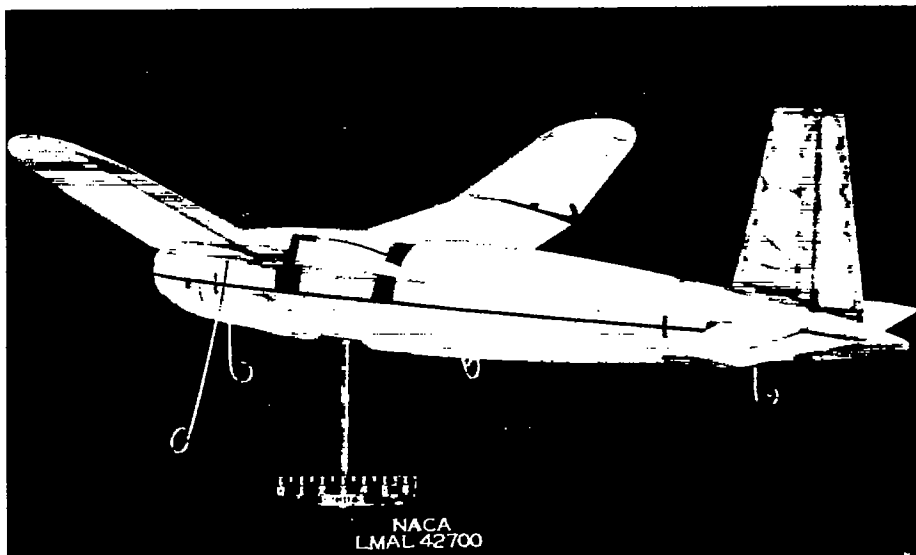


(b) Half-span-dihedral model.

Figure 3.- Front view of models used in tip-dihedral investigation.



(a) Quarter-span-dihedral model.



(b) Half-span-dihedral model.

Figure 4.- Three-quarter rear view of models used in tip-dihedral investigation.

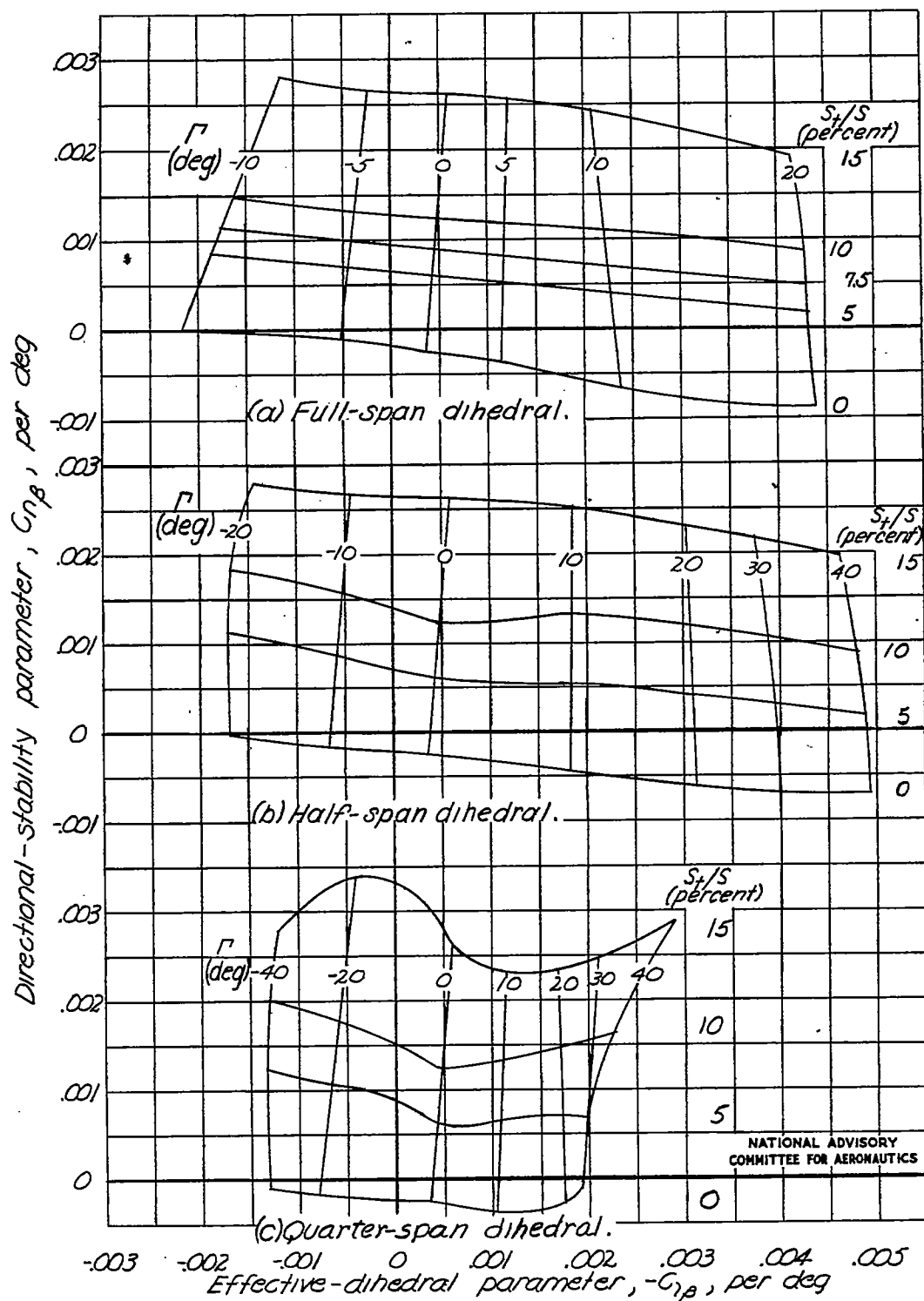


Figure 5.-Comparison of lateral stability derivatives for models with various spanwise dihedral-break locations. $C_L = 1.0$.

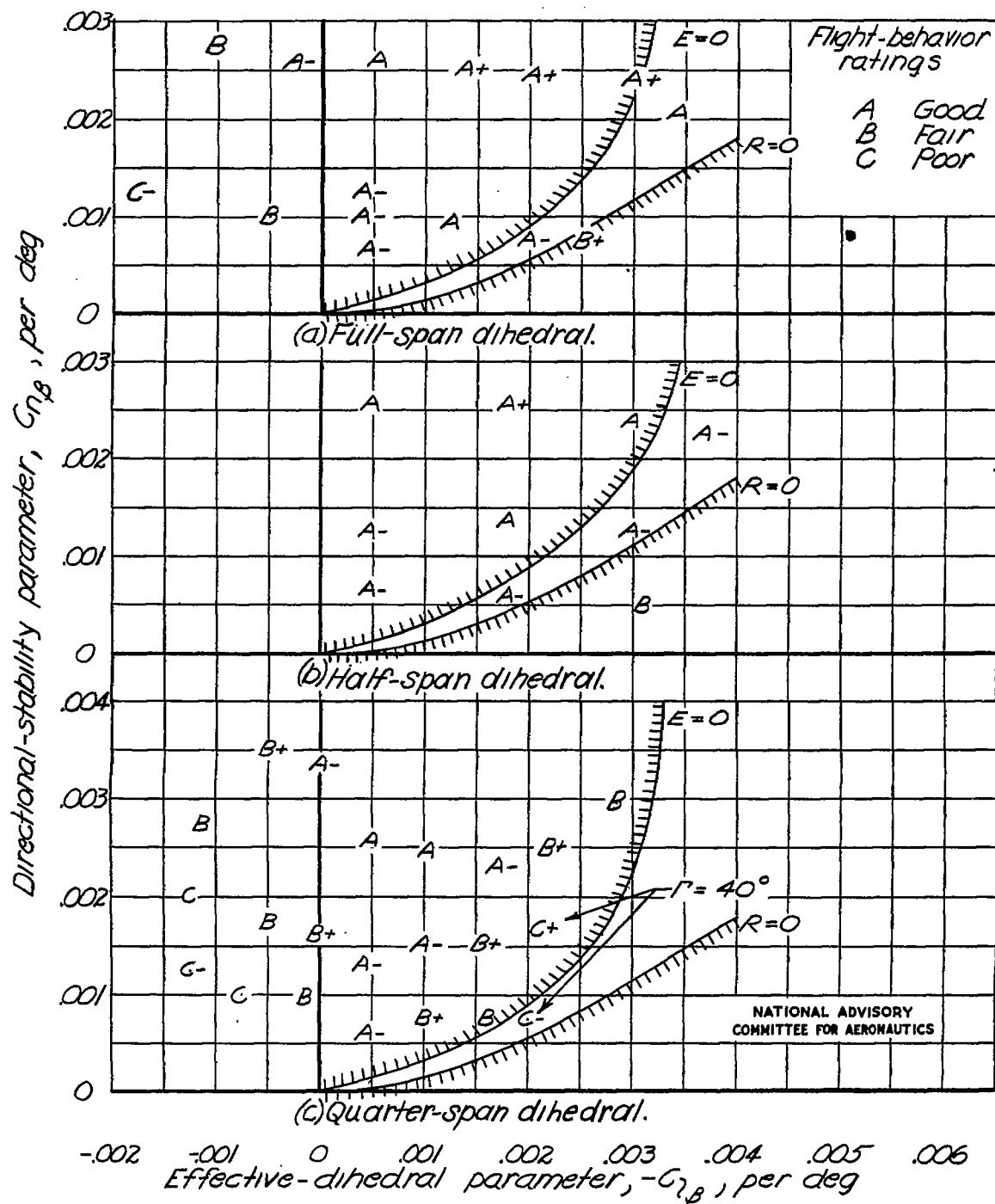


Figure 6.- General flight-behavior ratings with calculated spiral and oscillatory boundaries for models with various spanwise dihedral-break locations. $C_L = 0.1$.

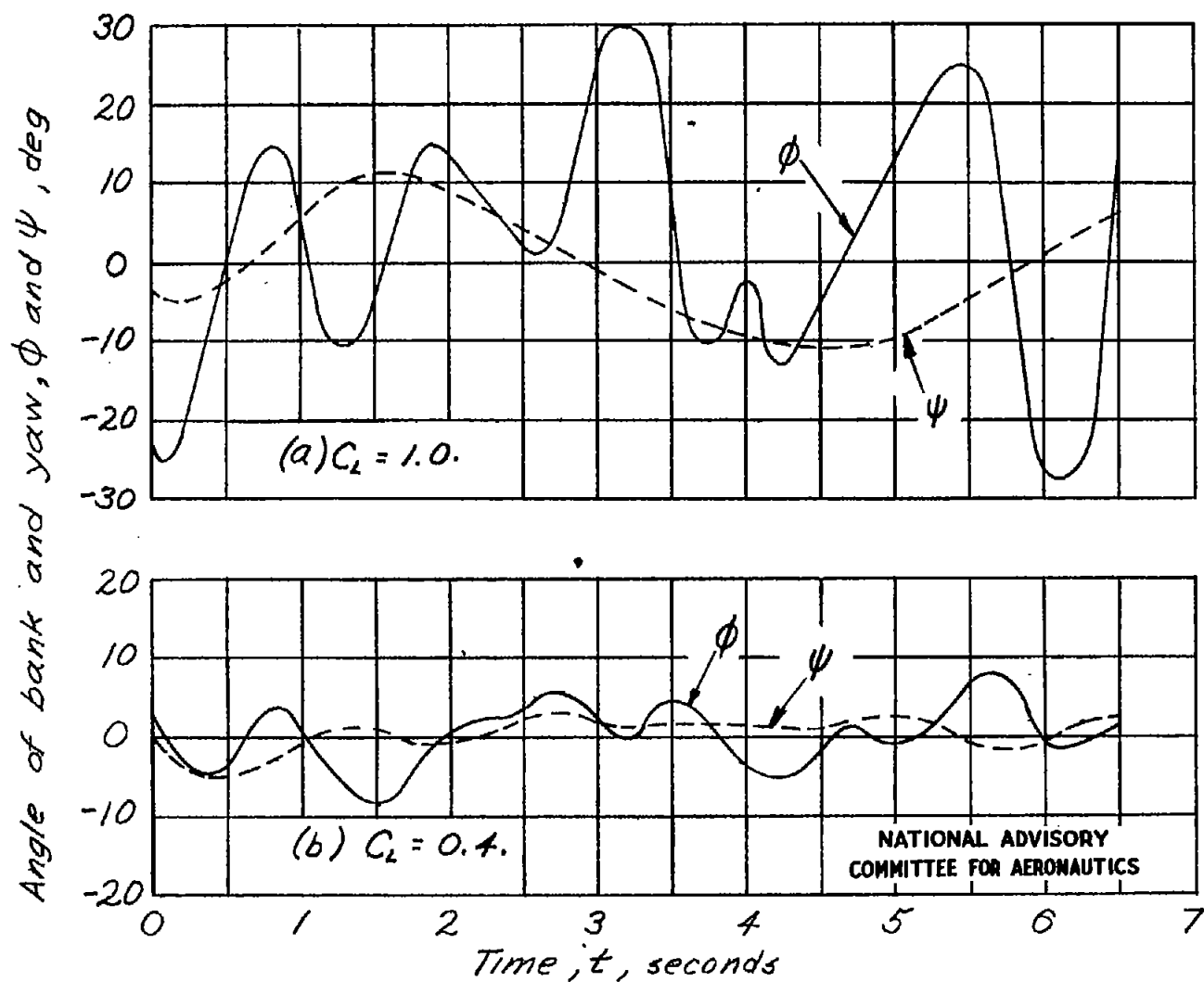
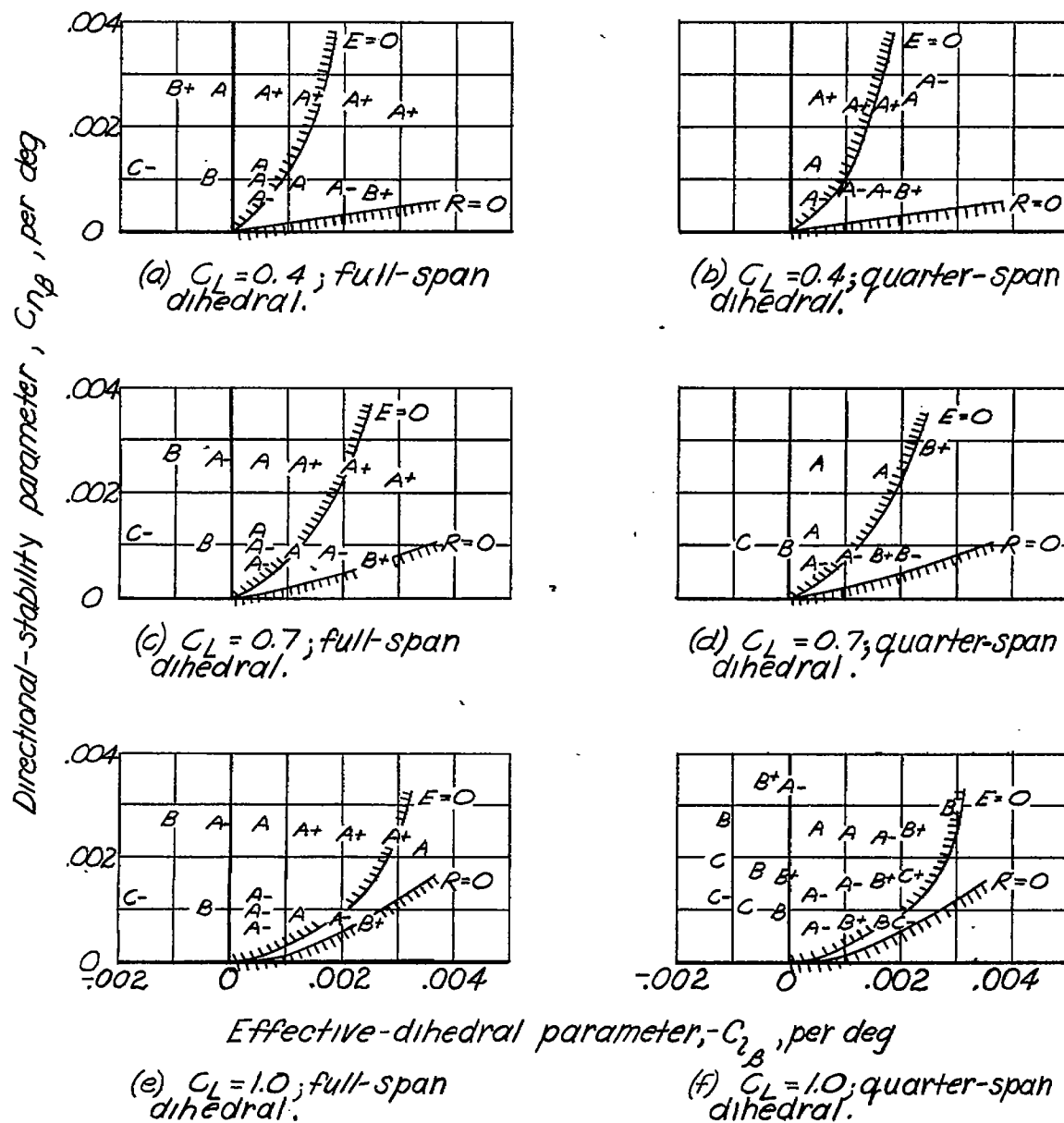


Figure 7.- Time history of flights of a model with 40° tip dihedral at high and low lift coefficients.

Flight-behavior ratings

A Good
B Fair
C Poor



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Figure 8.- Comparison of lateral-flight characteristics of a model with full-span dihedral and tip dihedral at varying lift coefficients.

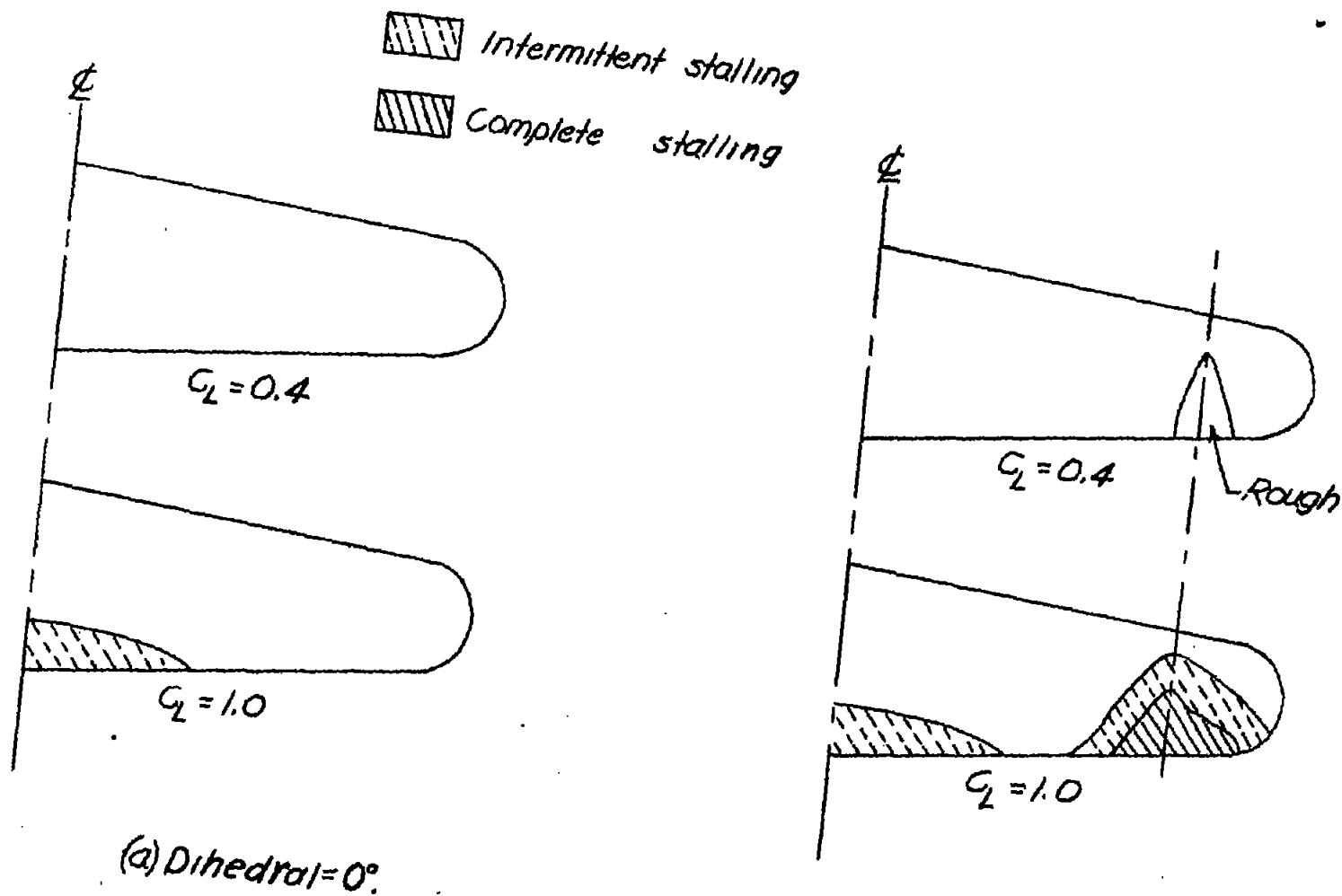


Figure 9.- Stall patterns for models used in tip-dihedral investigation.

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